PATENT SPECIFICATION (11) 1 592 196

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(21) Application No. 34023/77 (22) Filed 12 Aug. 1977 (19)
(31) Convention Application No. 51/097367 (32) Filed 13 Aug. 1976 in
(33) Japan (JP)
(44) Complete Specification Published 1 Jul. 1981
(51) INT. CL.^{3} B21B 1/22 // G05B 24/02
(52) Index at Acceptance
G3N 278 374 383 385 BB1

(54) METHOD AND DEVICE FOR CONTROLLING SHAPE IN ROLLED-METAL PRODUCTS

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The present invention relates to methods and apparatus for controlling shape in relatively thick metal work pieces rolled by hot rolling mill stands.

An object of the invention is to reduce the number of rolling passes required to produce a given product, while maintaining a given crown (that is the difference between the centre thickness and the edge thickness of the rolled plate, sheet or other workpiece) and predetermined shape (that is waviness along the middle or edges).

In general, in order to control the dimensions of rolled metal products with rolling mill stands for rolling relatively thick plates or sheets, pass schedules are designed so that metal work pieces may be rolled into the desired dimensions in an optimum manner.

During the early passes of a thick work piece the plastic flow of the material is predominantly in a direction transverse to the direction of travel. Hence, the longitudinal elongation of the strip is small and the difference between the elongation of the middle and elongation of the edges, producing waviness of the middle or of the edges, known as "shape", is virtually negligible.

During later passes, after the work piece has been reduced to a certain critical thickness, the plastic flow tends to be predominantly longitudinal and the elongation of the edges may differ from that in the middle producing "shape" i.e. waviness at the edges or at the middle. Shape can be minimised by ensuring that the longitudinal elongation is the same at the edges as it is in the middle, i.e. that the material is uniformly elongated without altering the proportions of the cross section, but only reducing its size. One important criterion of the cross section is the crown ratio Cr/H, that is to say the ratio of the crown Cr (i.e. the difference between the thickness in the middle and the thickness at the edges) to the thickness H. It is found that if the crown ratio is kept constant during later passes, shape can be kept down to an acceptable level.

Thus, an extensively used method for determining the pass schedule for flatness control, is a system based on the principle of the "constant crown ratio". This method is based on the concept that a good flatness can be maintained as a result of making the crown ratio (Cr/H) constant at successive passes, which will cause the longitudinal elongation of the material to be the same throughout the width. In order to secure a constant crown ratio, the relationship between the rolling force and plate thickness at each pass, would be a linear relationship, and in general at passes in which flatness control is performed, rolling can be performed only at a rate equivalent to a fraction of the total capacity of the rolling mill. In other words, rolling efficiency drops. For the final pass, the rolling force will have to be reduced in order to minimise the crown of the product, thereby involving a further drop in rolling efficiency.

According to one aspect of the present invention, a method of controlling shape in rolled metal workpieces in a series of passes for each workpiece to produce a finished product having a predetermined crown, includes monitoring shape and thickness of a workpiece to determine the critical thickness at which plastic flow changes from predominantly transverse to predominantly longitudinal, resulting in degradation of

shape, controlling the rolling pressure of a similar workpiece when its thickness is in the vicinity of the said critical thickness to produce a crown ratio equal to the desired final value, thereafter subjecting the latter workpiece to a number of passes at higher rolling pressures than those required to maintain constant crown ratio, thereby producing degradation of shape, and, in a final pass, controlling the rolling pressure to produce the desired crown ratio and reduce shape to restore the desired flat condition.

In one form of the invention the critical thickness is less than the thickness at which the curve of maximum rolling torque intersects the curve of constant crown ratio equal to that desired in the finished product, and between these two thicknesses rolling in at least one pass is at higher pressures than those required to maintain constant crown ratio.

The invention from another aspect comprises apparatus for use in the rolling of metal workpieces to control shape by a method as referred to above to control shape in workpieces, the apparatus comprising means for detecting shape in a rolled workpiece; means for sensing the critical thickness of the workpiece at which shape exceeds a predetermined level; processing means which is responsive to the output signal from the critical thickness sensing means and which also receives signals representing the desired thickness and crown ratio of the finished product; and instruction means controlled by the processing means and controlling the working pressure exerted on a similar workpiece in such manner that in the pass providing critical thickness or in the pass preceding the said pass, the crown ratio is equal to that desired in the finished product; in a number of subsequent passes the rolling pressures are higher than those required to maintain constant crown ratio thereby producing degradation of shape; and in a final pass the rolling pressure is that required to produce the desired crown ratio and reduce shape to restore the desired flat condition.

Further features and details of the invention will be apparent from the following description of one specific embodiment, which will be given by way of example with reference to the accompanying drawngs; in which

Figures 1 and 2 are graphs illustrating the relationship between the rolling pressure and the thickness of a rolled workpiece employing a known system 'A' and a system 'B' in accordance with the invention; and

Figure 3 is a block diagram of an apparatus for controlling shape in rolled metal workpieces in accordance with the invention.

In each of Figures 1 and 2, the curves "A1" and "A2" represent the relationship of rolling pressure to thickness in a known system, the small circles indicating successive passes. Along the curve "A1" the rolling force mainly determined by the maximum capacity of the mill motor, increases with the decrease of the thickness, due to the fact that the hardness of material is decreased due to high temperature, and the reduction force must be lowered since the output torque of the motor is limited. Until it has been reduced to a critical thickness 'Hc' the plate remains flat, that is, shape is zero, even if plate crown changes. As indicated above, this is due to the fact that the plastic flow occurs predominantly in a transverse direction and there is no substantial difference between the longitudinal extension of the outer edges and the longitudinal extension of the middle, which would cause shape to be greater than zero. After the plate has been reduced to the critical thickness 'Hc', plate shape has an intimate relation to plate crown since the plastic flow is primarily in a longitudinal direction and is not generally uniform across the width of the plate. Wrinkling may therefore occur along the edges or along the middle. As indicated above, this is known as 'shape' and can be minimised by controlling the rolling pressure so that the crown ratio is constant.

Such a schedule is indicated by the curve 'A2' but it will be appreciated that in prior arrangements the value of 'Hc' is not known and hence a transition from the curve 'A1' to the curve 'A2 is made at the intersection of the curve 'A1' with a prolongation of the curve 'A2' that is to say when the crown ratio arrived at by following the curve 'A1' reaches the desired value of the final product. This may happen to occur close to the critical thickness 'Hc' as indicated in Figure 1, but bearing in mind that the value of 'Hc' is not known in prior arrangements, it is more likely that the intersection of the curves 'A1' and 'A2' will occur at a thickness differing from 'Hc' as shown in Figure 2.

In the arrangement in accordance with the invention, the apparatus is initially set to an estimated value of 'Hc' and an initial workpiece is rolled while shape is monitored in the manner described below with reference to Figure 3. A signal is given when the value of shape exceeds zero by a predetermined minimum amount, and the thickness at which this occurs is stored and applied to the apparatus as a correction before the next workpiece is rolled.

The invention is primarily concerned with what occurs after each workpiece reaches the critical thickness 'Hc' since prior to this shape will not be degraded as the extension is predominantly transverse. If, as shown in.

Figure 1, the intersection of curves 'A1' and 'A2' occurs close to the critical thickness 'Hc' the schedule in accordance with the invention, like the known schedules, will follow the curve 'A1' up to this point. If on the other hand, as shown in Figure 2, the intersection is at a substantially greater thickness 'Hm', the rolling from the thickness 'Hm' to the critical thickness 'Hc' may follow any desired line. Preferably, however, the curve lies above the adjacent portion of the curve 'A2' so as to increase the reduction per pass, reducing the number of passes required to reach the critical thickness 'Hc' for example as indicated in Figure 2 from three to two.

In either case, in accordance with the invention, the crown ratio must be equal to that desired in the finished product at the critical thickness 'Hc'. Thus, at this particular point the curve 'B2' coincides with the curve 'A2'. Thereafter the rolling follows the curve 'B2'. This, it will be noted, lies above the curve 'A2' so that higher rolling pressures are employed and the number of passes, indicated by the little circles, required to reach the desired final thickness, is reduced.

The result of this is that shape is degraded i.e. increased throughout the passes of the curve 'B2, except the last one. The final pass of the curve B2 corresponds to the final pass of the curve 'A2' and is designed to result in a finished product having the desired crown ratio equal to that at the critical thickness, and at the same time negligible shape, or satisfactory flatness.

If the estimated value 'Hc' in Figure 1 is confirmed to coincide with the actual value of 'Hc' by the detection of the Figure 3, process, the curve 'B1' is omitted and the rolling is continued in accordance with curves 'A1' and 'B2' of Figure 1.

Figure 3 is a block diagram of one form of apparatus for controlling the rolling pressure in accordance with the invention.

A metal workpiece 3 is rolled by a four-high rolling-mill stand including upper and lower working rolls 1, upper and lower backup rolls 2, and screw-down gearing 4 driven by a reduction motor 5. TV camera heads 6 and 7 of a means for optically detecting the flatness of shape of the rolled-metal workpiece 3, such as a known optical shape meter, are positioned at the entry and leaving sides, respectively, of the rolling mill stand.

These TV camera heads 6 and 7 and a control unit 8 of an optical shape meter or the like make up the optical shape detection system. The output 'Si' from the control unit 8 representing shape of the rolled-metal workpiece 3 is fed into a correction or compensation unit 9.

A gauge or thickness sensor 10 detects the instantaneous gauge or thickness 'Hi' of the metal workpiece leaving the working rolls 1 and generates a signal 'Hi' which is fed into the correction or compensation unit 9. In response to this output 'Hi' from the gauge or thickness sensor 10, the correction or compensation unit 9 corrects or compensates the output 'Si' from the control unit 8 to generate the output 'Hc' representing a corrected or compensated critical gauge or thickness. In other words, the output from the correction or compensation unit 9 represents a gauge or thickness of the metal workpiece 3 at which shape will be degraded.

The output Hc from the correction or compensation unit 9, as well as the output from a second processing unit 12 to which are fed the signals representative of the desired gauge or thickness HF and crown CrF of the finished product, are fed into a first processing unit 11 which corrects or compensates the pass schedule at the gauge or thickness Hc.

The output of the first processing unit 11 is fed into an instruction unit 13 which accumulates the signal representative of the corrected or compensated pass schedule and generates the signal representative of the rolling pressure for the next pass.

That is, the output from the instruction unit 13 is transmitted to the reduction motor 5 so that the screw-down gearing 4 may be driven to a suitable position at which the working rolls 1 exert an optimum rolling pressure.

For the first workpiece an estimated value of Hc is employed and the rolling pressure is adjusted to follow the curve B1 of Figure 2. At the pass where the thickness is substantially equal to Hc the force PC is exerted which maintains the crown ratio equal to the desired value CrF/HF of the finished product, as set into the processing unit 12.

The output Si, representing shape in the rolled metal workpiece 3 provided by the optical shape detection system, is transmitted to the correction or compensation unit 9. In case of a pass with a gauge or thickness greater than Hc, the output Si is zero. On the other hand, in case of a pass with a thickness or gauge not exceeding the thickness Hc, the output signal Si is always present so that the thickness sensor 10 outputs to the unit 9 the signal Hi representative of the gauge or thickness of the metal workpiece at which the output Si is generated. As a result, the thickness Hc is correctly detected. Thus Hc is equal to Hi when the initial output signal Si first exceeds a minimum level Smin greater than zero. The output Si is always compared in the correction or compensation unit 9 with the signal Smin, and Hc is the thickness of the pass just prior to the pass in which the

output signal Si exceeds Smin for the first time.

In other words, at the gauge or thickness Hc, the rolling pressure becomes the rolling pressure Pc which results in the plate crown Crc which in turn maintains a constant crown ratio.

Again for the final pass the pressure is controlled to give the desired crown ratio of the finished product, as well as satisfactory flatness or lack of shape at the desired thickness.

With this new or corrected pass schedule the next metal workpiece is rolled.

The output signal from the first processing unit 11 is accumulated in the instruction unit 13, and the instruction signal is transmitted to the control motor 5 of the screw-down gearing 4 immediately before the next metal workpiece enters the working rolls 1 so that a predetermined rolling pressure may be produced. Therefore the finished metal product may have predetermined shape SF and predetermined plate crown Crf.

When the succeeding metal workpiece is equal in thickness to the preceding metal workpiece, the pass schedule corrected or compensated based on the rolling of the preceding metal workpiece and Hc may be further corrected or compensated from the results of the succeeding metal workpiece.

It is to be understood that the present invention is not limited to the preferred embodiment described above with reference to Figures 1 to 3 and that various modifications may be effected. For instance, the method and device in accordance with the invention may be equally applied to any types of rolling-mill stands.

WHAT WE CLAIM IS:-

1. A method of controlling shape in rolled metal workpieces in a series of passes for each workpiece to produce a finished product having a predetermined plate crown, which includes monitoring shape and thickness of a workpiece to determine the critical thickness at which plastic flow changes from predominantly transverse to predominantly longitudinal, resulting in degradation of shape, controlling the rolling pressure of a similar workpiece when its thickness is in the vicinity of the said critical thickness to produce a crown ratio equal to the desired final value, thereafter subjecting the latter workpiece to a number of passes at higher rolling pressures than those required to maintain constant crown ratio, thereby producing degradation of shape, and in a final pass controlling the rolling pressure to produce the desired crown ratio and reduce shape to restore the desired flat condition.

2. A method as claimed in Claim 1 in which the critical thickness is less than the thickness at which the curve of maximum rolling torque intersects the curve of constant crown ratio equal to that desired in the finished product, and between these two thicknesses rolling in at least one pass is at higher pressures than those required to maintain constant crown ratio.

3. Apparatus for use in the rolling of metal workpiece to control shape by a method as claimed in Claim 1 or Claim 2 comprising; (a) means for detecting shape in a rolled workpiece; (b) means for sensing the critical thickness of the workpiece at which shape exceeds a predetermined level; (c) processing means which is responsive to the output signal from the critical thickness sensing means and which also receives signals representing the desired thickness and crown ratio of the finished product; and (d) instruction means controlled by the processing means and controlling the working pressure exerted on a similar workpiece in such manner that; (1) in the pass providing critical thickness or in the pass preceding the said pass, the crown ratio is equal to that desired in the finished product; (2) in a number of subsequent passes the rolling pressures are higher than those required to maintain constant crown ratio thereby producing degradation of shape and (3) in a final pass the rolling pressure is that required to produce the desired crown ratio and reduce shape to restore the desired flat condition.

4. A method of controlling shape in rolled metal products in the rolling thereof, substantially as specifically described herein with reference to Figure 3 of the accompanying drawings.

5. Apparatus for use in the rolling of metal products for controlling shape in the products, substantially as specifically described herein with reference to Figure 3 of the accompanying drawings.

KILBURN & STRODE,
Chartered Patent Agents,
Agents for the Applicants.

Printed for Her Majesty's Stationery Office, by Croydon Printing Company Limited, Croydon, Surrey, 1981. Published by The Patent Office, 25 Southampton Buildings, London, WC2A 1AY, from which copies may be obtained.

1592196 COMPLETE SPECIFICATION

2 SHEETS *This drawing is a reproduction of the Original on a reduced scale*

Sheet 1

Fig. 1

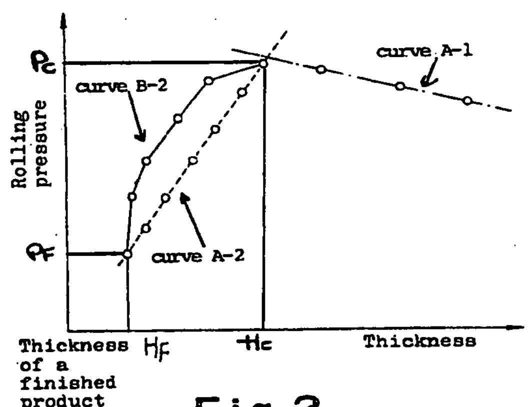

Fig. 2

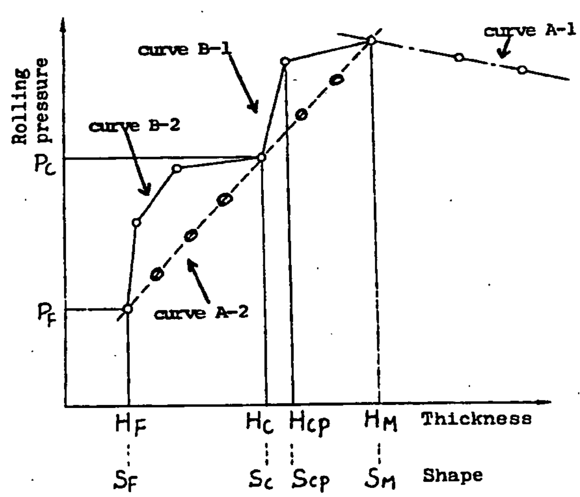

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Fig. 3